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DESIGN AND IMPLEMENTATION OF ULTRA-WIDEBAND BASED TRACKING SYSTEM

Abhijith Sai Chinni [1], Ankith M[1], Ravishankara M N[2]
UG Student[1], Associate Professor[2]
Department of Electronics and Communication Engineering,
Sapthagiri College of Engineering, Bengaluru,
Affiliated to Visvesvaraya Technological University, Belagavi.

ABSTRACT

This study in industrial and warehouse environments, precise and real-time asset tracking is essential for efficient logistics, inventory management, and operational optimization. This paper presents an Ultra-Wideband (UWB)-based real-time asset tracking system utilizing DWM1001C modules as anchors and tags with Raspberry Pi Zero 2W as a mobile attached tag to achieve high accuracy localization. The system employs the Time Difference of Arrival (TDoA) positioning method to determine asset locations with centimeter-level precision. The proposed system utilizes a button-triggered event-based tracking mechanism, optimizing power consumption while ensuring real-time tracking. A structured database (MySQL/Firebase) is integrated for location data storage and retrieval, enabling historical tracking and predictive analytics. Performance evaluation demonstrates high accuracy, low latency, and improved power efficiency. Future enhancements include AI-driven predictive tracking, cloud-based data integration, and mobile application support. This research establishes UWB as a viable solution for scalable, low-latency, and high-precision industrial asset tracking applications.

Keywords:
Ultra-Wideband, UWB, Real-Time Asset Tracking, DWM1001C, Raspberry Pi Zero 2W, Time Difference of Arrival (TDoA), IoT, MySQL, Localization, Industry 4.0, Database, Tracking systems, Asset, warehouse tracking, indoor tracking.

INTRODUCTION

Effective asset tracking is essential across various industries to optimize operations, reduce losses, and enhance security. Traditional methods like barcodes and RFID have limitations, including manual dependency, interference issues, and reduced accuracy in complex environments.

Ultra-Wideband (UWB) technology offers a superior alternative by providing real-time high-precision tracking with centimeter-level accuracy. As an IEEE 802.15.4a and IEEE 802.4z-compliant technology, UWB ensures reliable tracking in diverse indoor environments while maintaining low power consumption.

This study explores the implementation of a UWB based real-time location system (RTLS) using Decawave's DWM1001C modules. By overcoming the shortcomings of conventional tracking methods, this solution enables more efficient, scalable, and accurate asset management across multiple applications.

LITERATURE SURVEY

The development of real-time asset tracking systems has evolved significantly with the integration of Ultra-Wideband (UWB), RFID, GPS, BLE and other positioning technologies. This literature survey examines existing research on UWB based tracking and compares it with alternative methodologies.

A. UWB Based Tracking Systems

UWB has gained prominence due to its high accuracy, low latency, and robust performance in indoor environments. Several studies have explored UWB positioning techniques, network scalability, and real-time tracking applications.

Wenger [1] presented an indoor positioning system using a Raspberry Pi with UWB technology, which demonstrates submeter accuracy. The study focused on the implementation of ToA-based localization and

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evaluated performance across different warehouse layouts. The findings emphasized the ability of UWB to provide high-precision tracking while highlighting challenges such as multipath interference and anchor placement optimization.

Ni et al. [2] designed a UWB tracking system for free flying objects, integrating a multi-anchor network for precise localization. The system achieved centimeter-level accuracy, proving UWB's effectiveness for dynamic object tracking. However, the study identified network congestion problems when tracking multiple targets simultaneously, suggesting the need for efficient data synchronization algorithms.

Deepika and Prasad [3] analyzed high-precision UWB tracking based on open standard protocols, demonstrating improved scalability and interoperability. Their research proposed a hybrid tracking model that integrates UWB with external sensors to improve reliability.

Stocker et al. [4] investigated the security and scalability of UWB positioning, proposing encryption-based communication protocols to prevent signal spoofing. Their findings highlight the importance of secure data transmission in real-time tracking systems.

Tasbas et al. [5] demonstrated a real-time object tracking solution using UWB in an industrial indoor environment. Their study confirmed UWB's superiority over RFID and BLE in terms of precision and response time, but also noted deployment challenges due to anchor positioning constraints.

B. Optimization and Algorithmic Enhancements for Tracking

Enhancing tracking accuracy and system efficiency requires optimization techniques and robust algorithms. Several studies have proposed mathematical models and network optimization strategies to improve UWB tracking performance.

Laga Dwi Pandika et al. [6] applied the Floyd-Warshall algorithm for path optimization, to reduce asset retrieval time in warehouse environments. Their research demonstrated reduced latency in path computation, improving the efficiency of UWB-based navigation systems.

Corbal´an et al. [12] introduced Chorus, a concurrent UWB transmission framework that allows passive localization of multiple assets. Their system significantly reduced latency in large-scale tracking environments, making UWB a viable alternative to traditional active tracking solutions.

C. GPS-Based Tracking and Integration with UWB

While GPS remains the primary technology for outdoor tracking, its limited indoor usability has led to hybrid approaches combining UWB with GPS for enhanced performance.

O'Keefe et al. [7] investigated a tightly-coupled UWB and low-cost GPS solutions for vehicle-to-infrastructure positioning. Their research demonstrated that hybrid UWB-GPS systems improved accuracy in urban environments, overcoming GPS signal degradation issues.

Sato et al. [8] explored absolute positioning control of flying robots using ultrasonic waves and GPS, integrating sensor fusion techniques to enhance tracking stability. Their findings emphasized the importance of combining GPS with auxiliary positioning methods for real-time navigation.

Flores et al. [9] developed an ultrasonic sensor network for high-quality range-bearing indoor positioning, demonstrating an alternative approach for UWB-GPS hybrid tracking.

D. RFID and UWB Integration for Industrial Asset Tracking

RFID has been widely adopted for inventory management and asset identification, but it lacks real-time positioning capabilities. To address this limitation, researchers have explored RFID-UWB hybrid systems.

Huang et al. [11] proposed an RFID and UWB-based real-time location system (RTLS) for digital manufacturing workshops. Their system utilized RFID for identification and UWB for accurate position estimation, achieving high tracking accuracy while reducing deployment costs.

Schantz et al. [10] characterized error margins in near-field electromagnetic ranging RTLS, evaluating the performance of RFID-UWB integration in industrial settings. Their study demonstrated reduced tracking errors compared to standalone RFID systems.

E. BLE-Based Tracking and Comparison with UWB

Bluetooth Low Energy (BLE) has been considered for lowpower, short-range asset tracking. While BLE provides costeffective solutions, its accuracy is significantly lower than UWB.

Kripanithi et al. [13] proposed PLAN, an indoor positioning system using BLE with RSSI-based localization techniques. Their study found that BLE tracking achieved meter-level accuracy, making it suitable for zonal tracking applications but inadequate for precise asset localization.

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METHODOLOGY

A. System Architecture and Hardware Setup

The system consists of three main components:

- DWM1001c Modules - Functioning as UWB anchors and tags, responsible for sending and receiving UWB signals for positioning.
- Raspberry Pi Zero 2W – Serving as a mobile tracking unit, transmitting location data upon user interaction.
- MySQL/Firebase Database – Stores historical and real-time tracking data for analysis.

Fig. 1 represents the block diagram of the proposed system. It has all the components representation and placement order.

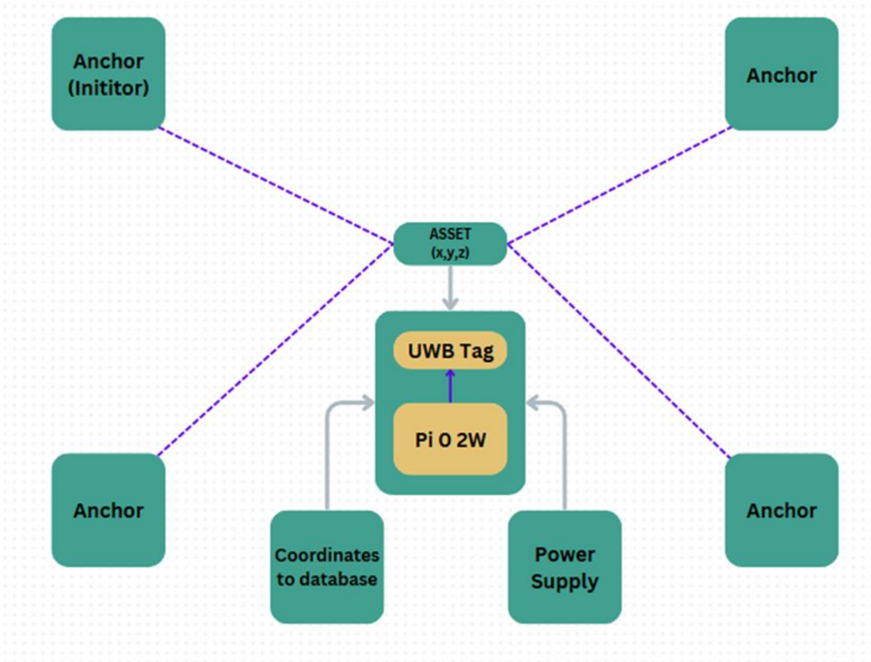

Figure 1: Block Diagram

B. Firmware and Network Configuration

For the UWB network to function efficiently, each DWM1001C module must be configured properly. The Positioning and Networking Stack (PANS) firmware is used to enable communication between anchors, tags, and the Raspberry Pi zero 2W.

1. Flashing PANS Firmware:
   - The latest PANS firmware is downloaded and flashed onto DWM1001C modules using Decawave's configuration tools.
   - The firmware allows UWB modules to operate in a TDoA-based positioning network.
2. Anchor and Tag Initialization:
   - DWM1001C Anchors are assigned unique IDs and network parameters.
   - The DWM1001C Tag (attached to RPi Zero 2W) is configured to transmit UWB pulses at fixed intervals.
3. Network Configuration:
   - A star or mesh topology is implemented, where anchors communicate with a central Raspberry Pi Gateway.
   - Serial communication (UART) between the Raspberry Pi Zero 2W and the DWM1001C tag is established.

C. Data Processing and Database Integration

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Once tracking data is collected, it must be processed, filtered, and stored efficiently. Data processing workflow:

- The Raspberry Pi Zero 2W requests a position update.
- The UWB tag transmits a pulse to the anchor network.
- The Raspberry Pi collects timestamped location data.
- Data is formatted into (X, Y, Z) coordinates based on TDoA calculations.
- The processed tracking data is sent to a MySQL database.
- Warehouse operators can retrieve location data for realtime monitoring.

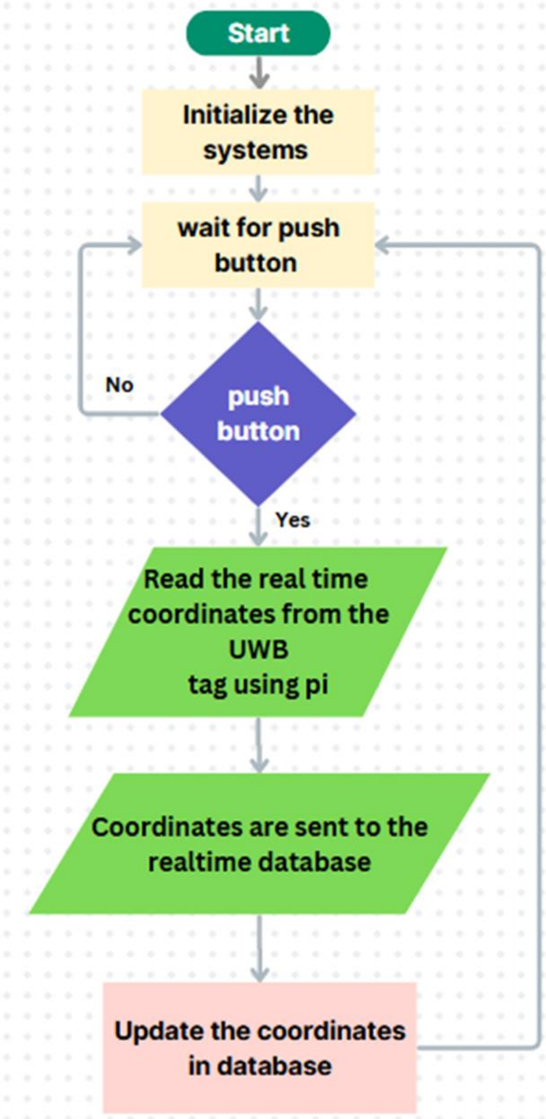

Figure 2: Flow Chart

Figure 2 represents the flowchat for the propsed systems, it shows how the process begins and ends.

RESULTS AND ANALYSIS

To measure positioning accuracy, a ground-truth reference system was used to compare the UWB-calculated coordinates with actual known positions of the tracked asset. The following testing conditions were considered:

- Open Space – Minimal interference, controlled environment like an empty room.

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- Obstructed Space – Shelving units, metallic obstacles, and signal reflections.

Table 1 and Table 2 below shows the comparisons of anchor environment and result comparisons of different such technologies respectively.

Test Case	Anchor Configuration	Actual Position	Measure Position
1	4 anchors	(2.0, 3.5, 1.85)	(2.1, 3.4, 1.85)
2	4 anchors	(4.5, 6.0, 1.2)	(4.5, 6.0, -1.4)
3	4 anchors	(6.0, 9.5, 2.0)	(6.1, 9.5, 2.3)

Table 1: Position Comparison Table

The above represented table shows the configuration data along with measured and actual values.

Feature	UWB-Based System	RFID-Based Tracking [11]	GPS-Based Tracking [12]
Accuracy	3-10 cm	30-50 cm	5-10 m
Indoor Tracking	Yes	Limited	No
Real-Time Updates	Yes	Yes	Delayed
Scalability	High	Moderate	Global Coverage
Power Efficiency	Optimized	High	Low

Table 2: Comparison Table of UWB with other tracking systems

High-precision indoor tracking using Ultra-Wide Band (UWB) devices with open standards demonstrated a real-time system for positioning in a bounded environment. The system used DWM1001C devices, where a minimum of four anchors were required to track a single tag. The system achieved accurate Cartesian coordinates. The below Figure 3 shows the sample data received from the terminal of a 4 anchor and single tag configuration. Below are a few important points:

- Accuracy: Achieved up to 30 cm position error in indoor environments.
- Effect of Obstacles: Human presence significantly increased signal interference and error rates.
- Interference Handling: Robust against multi-path interference due to energy-efficient techniques.
- Offline Mapping: Performed well in sparse environments but showed reduced reliability with more individuals.
- Technology Performance: Used 500 MHz UWB with TDoA techniques, achieving a 20 m range in both LoS and NLoS conditions.
- Bandwidth and Modulation: Operated within 3.5–10 GHz using BPSK/QPSK, ensuring high data throughput.
- System Efficiency: Multiple anchors improved tracking accuracy and overall system performance.

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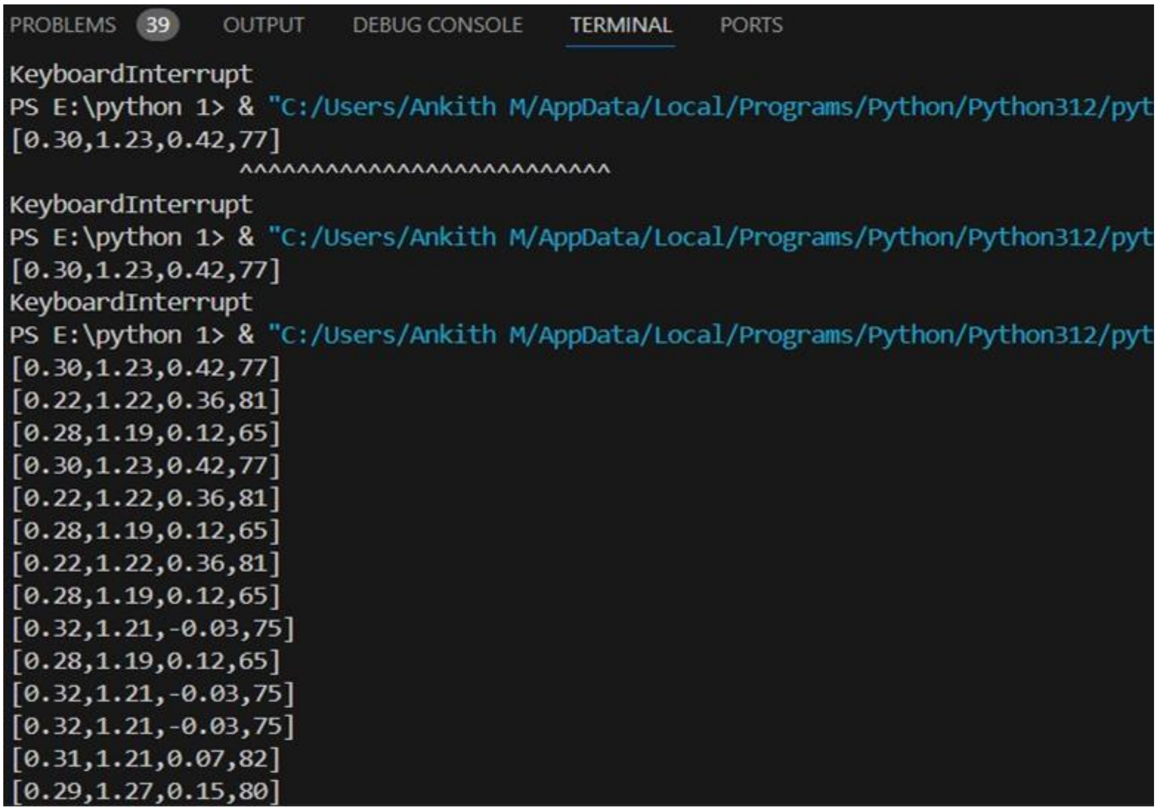

Figure 3: Results

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CONCLUSION

The UWB-based tracking system offers high accuracy, efficiency, and scalability for real-time asset monitoring across various applications. It enables seamless integration, and enhanced visibility, improving operational performance. Future advancements include AI-powered predictive analytics for anomaly detection, optimization, and AR-assisted navigation. While challenges like adoption and scalability exist, modular design and improved UWB chips ensure adaptability. This system lays the foundation for AI-driven automation, setting A new standard for accuracy and efficiency in asset tracking across industries.

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